

**The Effect of Turbidity on the Solar Resetting  
of the Luminescence Signal:  
Implications for Luminescence Geochronology**

**A Senior Honors Thesis**

**Presented in Partial Fulfillment of the Requirements  
for graduation with distinction in Geological Sciences  
in the undergraduate colleges of The Ohio State University**

**by**

**Kenneth Errol Lepper**

**The Ohio State University  
March 1995**

**Project Advisor: Dr. Steven Forman,  
Byrd Polar Research Center**

**The Effect of Turbidity on the Solar Resetting  
of the Luminescence Signal:  
Implications for Luminescence Geochronology**

- - -

**Abstract**

**Section 1: Introduction**

- 1.1 General Introduction**
- 1.2 Basic Principles associated with Luminescence Dating**
- 1.3 Properties of Turbulent Water Systems that make Waterlain  
Sediments Problematic for Luminescence Dating**
- 1.4 The Goals of the Study**

**Section 2: General Procedures**

- 2.1 Experimental Apparatus: "The Turbidity Tube"**
- 2.2 Characterization of the Sediment Sample**
- 2.3 Sample Preparation and Experimental Procedures**
- 2.4 Data Collection**
  - 2.4.1 Thermoluminescence data collection
  - 2.4.2 Infrared stimulated luminescence data collection
  - 2.4.3 Red stimulated luminescence data collection
- 2.5 Data Analysis**

**Section 3: Results / Discussion**

- 3.1 The Effect of Sediment Concentration on Solar Resetting**
- 3.2 The Effect of Flocculation on Solar Resetting**
- 3.3 Comparative Sensitivity of Luminescence Stimulation  
Techniques**

**Section 4: Conclusion**

**The Effect of Turbidity on the Solar Resetting  
of the Luminescence Signal:  
Implications for Luminescence Geochronology**

**Abstract**

Quantitative determinations of the effect of sediment concentration on the extent of solar resetting of the luminescence signal within suspended sediments in a laboratory simulation of a turbid water system are made using thermoluminescence [TL], infrared stimulated luminescence [IRSL], and red stimulated luminescence [RedSL]. The results show a general, but non-linear, increase in residual luminescence with increasing suspended sediment concentration for TL, IRSL, and RedSL. Results of this investigation demonstrate flocculation to be a significant process contributing to residual luminescence in waterlain sediments. The results of the investigation question the reliability of TL to provide accurate age determinations for waterlain sediments, and indicate IRSL may be applicable to date sediments deposited in low concentrations ( $\leq 10$  mg/L), but offers no significant advantages over TL for dating sediments deposited in higher concentrations. Comparison of the TL, IRSL and RedSL data shows the RedSL signal to be the most sensitive of the three to solar resetting through turbid water and highlights the future utility of red stimulated luminescence to date a wide range of waterlain sediments.

**Section 1: Introduction**

**1.1 General Introduction**

The Quaternary is a period of dynamic climate change: perhaps 20 oscillations between cooler glacial stages dominated by vast ice sheets and warmer interglacial stages such as the present. A sound chronology of Quaternary environmental change is crucial for interpretation of the past. A rich record of environmental change is recorded in sediments that were deposited during the time interval between the effective age ranges of established dating methods such as radiocarbon dating and K-Ar dating. Luminescence dating holds the potential to bridge the temporal gap between other dating

methods and become an important tool for understanding the chronology of environmental change in the Quaternary Period.

Thermoluminescence is recognized as a fundamental property of crystalline insulators<sup>1</sup> [minerals<sup>2</sup>] to emit light upon heating (<sup>1</sup>Aiken, 1985; <sup>2</sup>Klein & Hurlbut, 1985). Luminescence dating is an experimental technique developed from the thermoluminescence property of minerals. Luminescence dating can be used to determine the age of Late Quaternary sediments based on controlled quantitative laboratory measurements of light emitted from excited mineral grains. Luminescence age determinations are made directly from sediment grains therefore its applications are not restricted to deposits that contain organic material. The effective age range of luminescence dating is from approximately 1,000 years B.P. to greater than 250,000 years B.P.

The Quaternary geologic applications of luminescence dating are currently limited to specific types of sedimentary deposits (i.e. eolian) or to deposits with unique stratigraphic relations (i.e. sediments beneath lava flows). Extending the application of luminescence dating to waterlain sediments is crucial because Quaternary glacial-marine, estuarine, and lacustrine deposits contain important records of climate change. However, waterlain sediments are particularly problematic for the application of luminescence dating due to the attenuation of solar energy through sediment-laden water and the complex behavior of sediment particles in turbid water systems. This investigation will

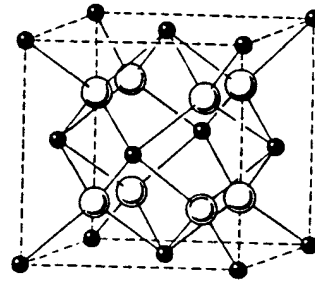
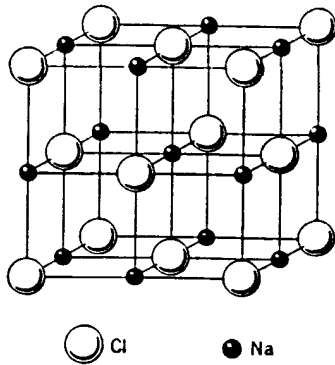
provide a quantitative determination of the effect of sediment concentration on the resetting of the luminescence signal in sediment grains within a turbid water system. The results of this investigation will help determine the depositional environments appropriate for application of luminescence dating, as well as to aid in development of new experimental procedures for luminescence dating of waterlain sediments.

## **1.2 Basic Principles associated with Luminescence Dating**

All minerals, regardless of their size, are composed of a regular, repeating arrangement of atoms forming a crystalline lattice (Fig. 1). Ionizing radiation from the radioactive decay of naturally occurring isotopes (such as uranium, thorium, and potassium-40) and cosmic radiation can penetrate the lattice and displace electrons from orbitals within mineral grains. The displaced electrons are often "trapped" within crystal defects or irregularities such as anion vacancies or cation substitutions in the lattice (Fig. 2). Over geologic time this process results in the accumulation of a stored electron signal (Aiken, 1985). Heat, light, pressure and chemical interactions supply internal energy to the mineral lattice that may release stored electrons from trap sites. Luminescence arises when freed electrons recombine with cations and emit photons of discrete energies.

In the laboratory either heat, thermoluminescence (TL), or light, optically stimulated luminescence (OSL), can be used to excite the mineral lattice and initiate the un-trapping and recombination process. The resulting photon emission

The structure of halite.



The structure of fluorite.

Figure 1. The crystal structure of halite and fluorite; showing the regular, repeating arrangement of atoms characteristic of all minerals (from Klein and Hurlbut, 1985).

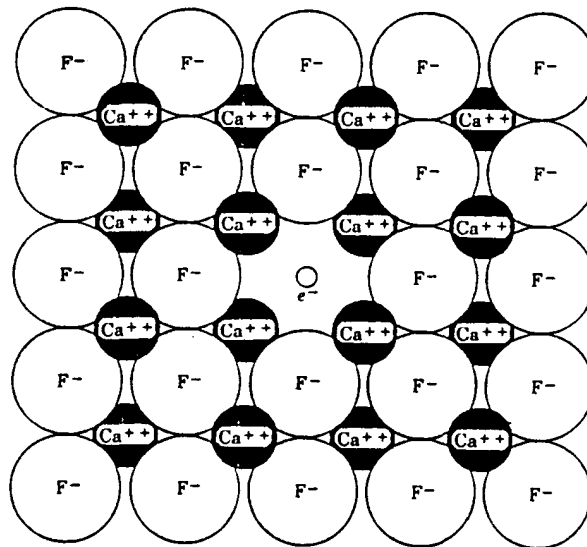


Figure 2. Anion vacancy is a common type of crystal defect. This figure shows an electron occupying the site of a missing fluorine ion in the mineral structure of Fluorite (from Klein and Hurlbut, 1985).

intensity can be measured and is referred to as the luminescence signal.

In nature, mineral grains that will eventually become sediments or sedimentary rocks go through a dynamic cycle of erosion, transport, and deposition (ETD cycle, Fig. 3). Erosion and transportation are the geologic processes that expose sediment grains to sunlight which depletes the stored electron signal and serves to reset the 'luminescence clock'. Deposition shields the grains from further solar exposure and permits the 'luminescence clock' to restart. The extent of solar resetting that occurs is primarily a function of the intensity of solar radiation received and the light exposure time of the sediments. If the stored electron signal is not completely reset during an ETD cycle, a residual signal may be retained after deposition. Thus, the luminescence signal recorded in the laboratory may not only reflect the time since the last depositional event but may also include one or more residual signals. Residual signals erode the accuracy of calculated ages, resulting in over-estimates of the time since sediment deposition.

### **1.3 Properties of Turbid Water Systems that make Waterlain Sediments Problematic for Luminescence Dating**

The accuracy of luminescence ages for waterlain sediments is dependent on the success of laboratory procedures to simulate the residual signal or to distinguish the residual signal from the true age-related signal. It is particularly difficult to establish laboratory procedures to accurately simulate the residual luminescence signal in fine-grained

## EROSION - TRANSPORT - DEPOSITION CYCLE

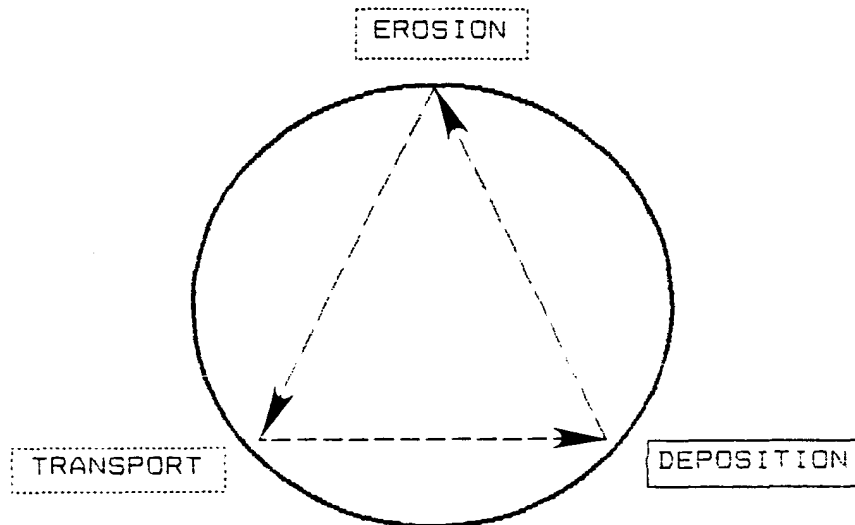


Figure 3. Diagram of the ETD cycle; depicting the cyclic and continuous action of erosion, transport, and deposition (after Stokes, 1992).



sediments transported in turbid water systems, due to attenuation of solar energy through water, flocculation of particles, and randomization of particles in turbulent systems.

Studies of the optical properties of ocean water have shown that the intensity of light of a given wavelength penetrating a column of water to a given depth ( $z$  in meters) is given by:

$$I_z = I_0 * \text{EXP}(-kz) \quad (\text{Pickard \& Emery, 1984})$$

where  $I_0$  is the intensity of that wavelength at the surface and  $k$  is the vertical attenuation coefficient.  $k$  is the sum of the attenuation of water ( $A_w$ ), the absorbance by suspended particles ( $A_p$ ), the scatterance by suspended particles ( $B_p$ ), and the absorbance of organic matter ( $A_y$ ):

$$k = A_w + A_p + B_p + A_y \quad (\text{Syvitski et al., 1987})$$

Because  $k$  is dependent on  $A_w$ , which varies with wavelength, and on variations in sediment concentration and sediment composition (terms  $A_p$  and  $B_p$ ), the intensity of sunlight penetrating turbid water compared to clear water is reduced, and attenuated in favor of longer, less energetic wavelengths (Fig. 4: Pickard & Emery, 1984).

Although these relationships were developed through oceanographic studies, it can be inferred that a similar reduction in relative energy and shift in peak intensity should occur in streams, lakes, or any system of turbid water.

Many researchers have recognized a qualitative relationship between increased suspended sediment concentration and reduced potential for solar resetting of the

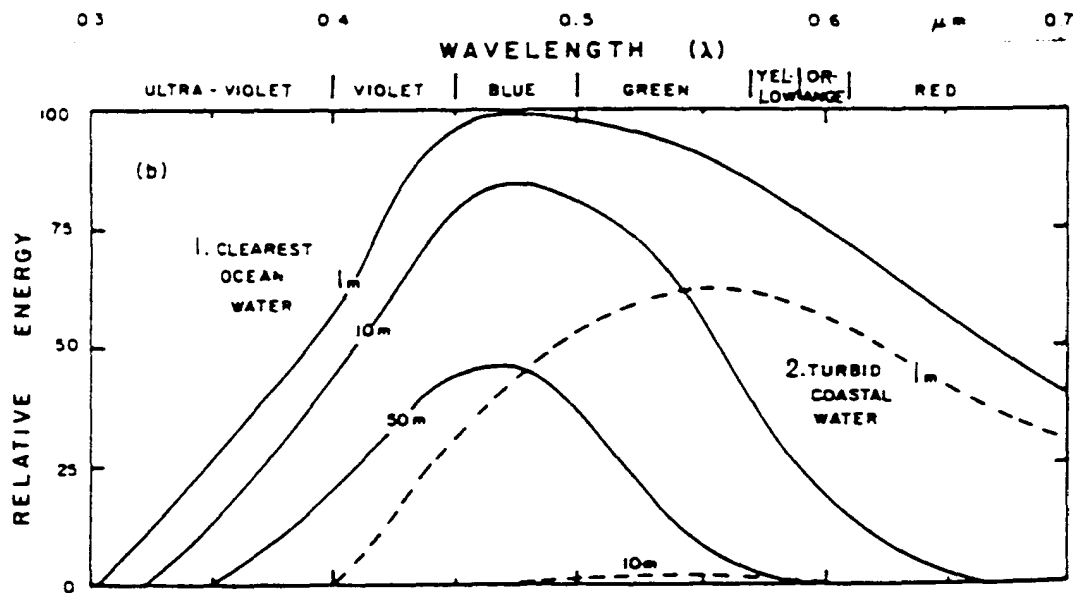


Figure 4. Graph illustrating the shift toward longer wavelength and the reduction in relative energy (intensity) of light penetrating one meter into turbid coastal water [dashed line] versus clear ocean water [solid line] (from Pickard and Emery, 1984).

luminescence signal within the sediment grains (Berger, 1988; Forman et al., 1989 & 1994; Stokes, 1992). Sediment transported in high concentrations may also be rapidly buried allowing less time for sunlight to reach individual grains.

Flocculation is another important natural process that affects the nature and duration of solar exposure of sediments in turbid water systems. The physical form of fine-grained sediments is often thin sheets or tiny spindles which easily become polarized. The composition of fine-grained sediments often includes a large quantity of clay-group minerals. Geochemical studies indicate that clay-group minerals are also easily polarized. The small polarized particles then exert an attractive force on one another, causing agglomeration into larger particles. The agglomeration of fine-grained sediments into larger particles is called flocculation. The flocculation process shelters grains on the inside of the growing mass from solar energy and also causes the growing particles to sink more rapidly through the water column thereby decreasing the amount of sunlight exposure of all the grains.

These factors make it very probable that many waterlain deposits are not completely reset by solar energy during their ETD cycle and retain some amount of residual luminescence signal at the time of deposition. Residual signal undermines the accuracy of and confidence in luminescence age determinations for waterlain sediments.

#### 1.4 The Goals of the Study

A previous investigation by Ditlefsen (1992) focused on the resetting of the luminescence signal in sand-sized sediment grains beneath a simulated turbid water column. The experiment developed by Ditlefsen quantifies the resetting of luminescence signal for bedload grains. However, suspended sediments move randomly throughout a turbulent water column and are exposed to more solar radiation than bedload grains, making mineral grains transported as suspended load better candidates for luminescence dating. This research was developed and conducted to quantitatively characterize the effect of varying sediment concentrations in a turbid water system on the extent of solar resetting of the luminescence signal within the suspended sediment grains.

Unlike the sand-sized sediments analyzed by Ditlefsen (1992), the fine-grained sediments used in this study are susceptible to flocculation. This research attempts to demonstrate the significant effect flocculation has on the resetting of the luminescence signal in fine-grained waterlain sediments.

The degree of solar resetting of the luminescence signal within suspended sediment grains was measured by three different luminescence stimulation techniques: heat stimulated or thermoluminescence (TL), infrared light stimulated luminescence (IRSL), and red light stimulated luminescence (RedSL). Comparison of the results from the three different techniques provides a means of comparing the

sensitivity of the techniques to detect solar resetting in sediment grains suspended in turbid water systems.

## **Section 2: General Procedures**

### **2.1 Experimental Apparatus: "The Turbidity Tube"**

A laboratory simulation of a turbid water column was devised to ascertain the effect of varying turbidity on the solar resetting of the luminescence signal. An apparatus was constructed in which known concentrations of sediment could be maintained in suspension during timed exposures to natural sunlight. A PVC cylinder containing a magnetic spin-bar was supported by a wooden structure; a stable arrangement that provided a continuous fluid circulation cell in a one meter deep water column. The apparatus was given the working name, "Turbidity Tube" (Fig. 5). The column was capped and returned to the luminescence dating laboratory after the appropriate exposure time had elapsed.

### **2.2 Characterization of the Sediment Sample**

The sediment sample selected for this investigation is a waterlain lacustrine silty-clay collected from rhythmically bedded deposits of Glacial Lake Missoula, northwest Montana. The sediment was selected for its abundance of silt-sized grains, its low organic content, and the strong natural luminescence signal it registered on all three measurement systems. Grain size analyses reported by Levish et al. (1993) for samples from the same lithofacies range from 33-44% silt, 56-67% clay and only a fraction of a percent sand.

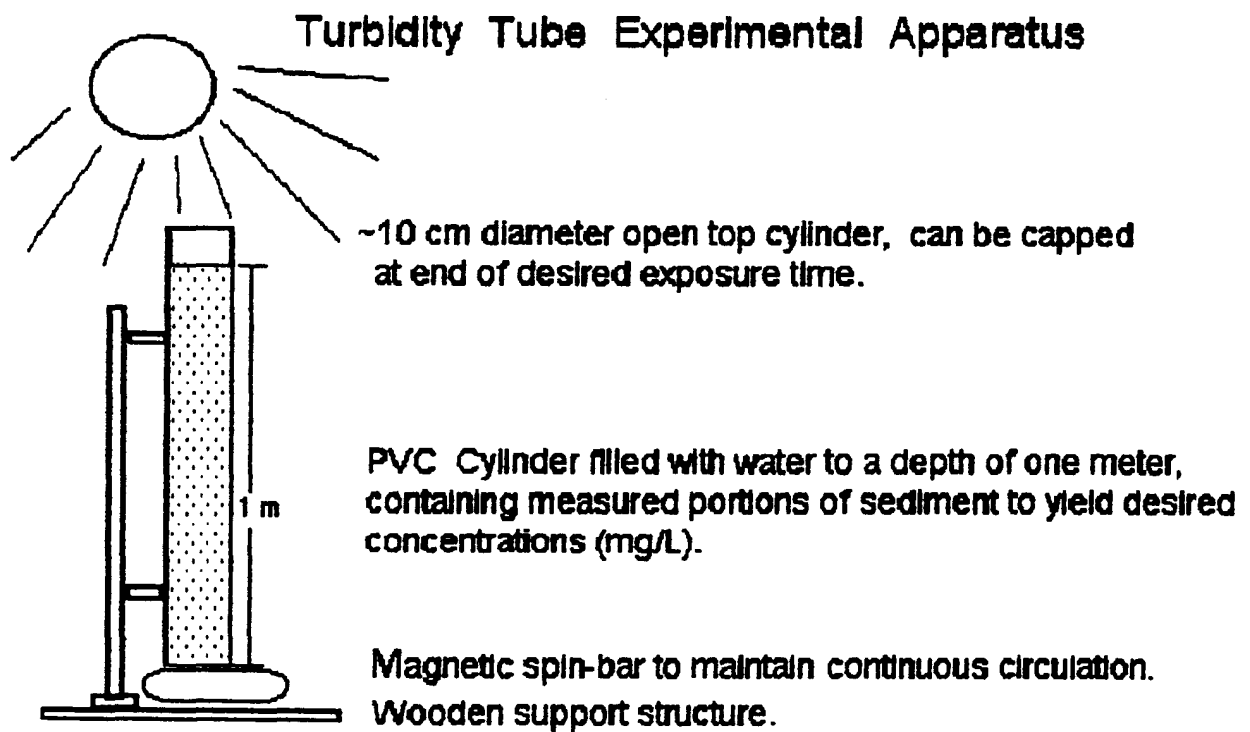


Figure 5. Diagram of the turbidity tube.

### 2.3 Sample Preparation and Experimental Procedures

All sample handling, preparation, and data collection took place in the luminescence dating laboratory. Sodium vapor lamps are used in the lab to provide low intensity, monochromatic (596 nm) lighting that has negligible erosive effect on the luminescence signal of samples (Pierson, unpublished data), but is readily perceived and utilized by the human eye. Only the timed experimental exposures were conducted outside of the lab.

An unexposed portion of the field sample was treated with 0.01 M HCl to remove calcium carbonate. The entire portion was rinsed with water then a portion was extracted to be prepared as the natural or control data set. This extracted portion was resuspended in a volatile carrier and plated onto aluminum disks to measure the natural luminescence signal.

The remainder was rinsed with methyl alcohol and allowed to dry in a light-protected cabinet. After drying, the sediment was carefully weighed out into parcels to provide sediment concentrations of 10,15,20,35,50,75, and 100 mg/L when suspended in the turbidity tube. In order to introduce the dry sediments evenly into the turbidity tube they were first suspended in 15 ml of water or 15 ml of 0.006 M sodium pyrophosphate solution. Sodium Pyrophosphate is a dispersant which inhibits the natural process of flocculation. Each sediment suspension was then added to the experimental cylinder and exposed to 4 hours of ambient sunlight while circulating in the turbidity tube. After exposure, samples

were returned to the lab, concentrated, and resuspended in a volatile carrier for plating onto aluminum disks.

## 2.4 Data Collection

### 2.4.1 Thermoluminescence data collection

Sample disks were heated from room temperature ( $\sim 25^{\circ}\text{C}$ ) to  $450^{\circ}\text{C}$ , in a nitrogen atmosphere, at a controlled rate of  $5^{\circ}\text{C}/\text{sec}$ . During the heating process the emitted luminescence signal intensity was measured by a photomultiplier tube and recorded as photon counts/sec. The photomultiplier tube was fitted with optical filters that transmit light in the ultraviolet to blue spectral range. The data are plotted as temperature versus thermoluminescence intensity (Fig. 6).

### 2.4.2 Infrared stimulated luminescence data collection

Sample disks were exposed to emissions from an infrared diode array for 90 seconds. The resulting luminescence emitted from the sample in the blue-green spectral range was measured by a photomultiplier tube and recorded as photon counts/sec. The photomultiplier tube was fitted with an optical filter that transmits light in the blue-green range while excluding light from the infrared range. The data are plotted as stimulation time versus luminescence intensity (Fig. 7).

### 2.4.3 Red stimulated luminescence data collection

Measurement of RedSL required the use of the newly developed variable narrow bandpass optically stimulated luminescence system (VNB-OSL). The VNB-OSL is a highly flexible system that can supply light throughout the visible spectrum to be used for sample stimulation (Pierson et al.,



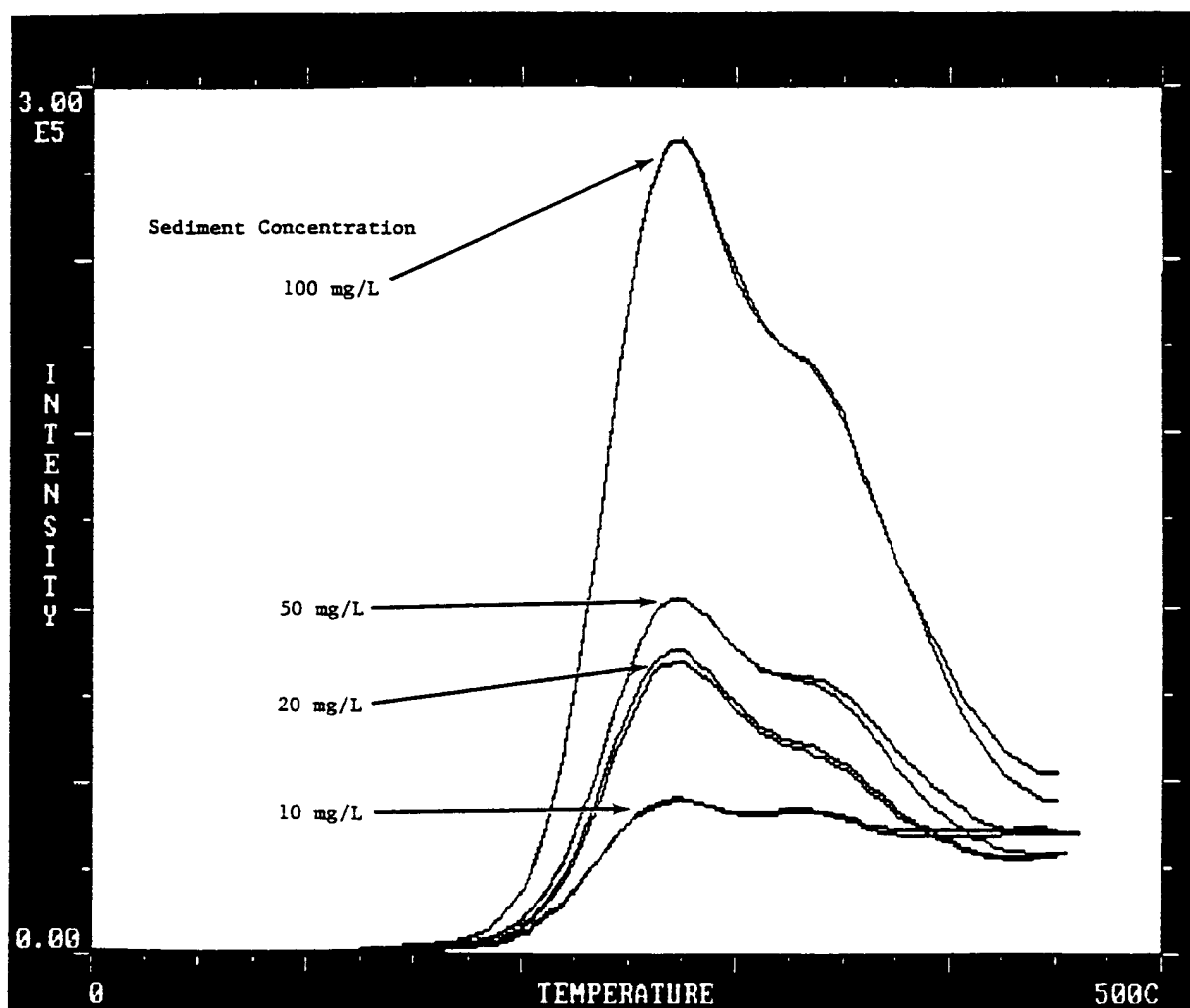


Figure 6. Example of thermoluminescence (TL) data collection curves. The data are plotted as temperature versus luminescence intensity. Two data curves are shown for each of the indicated sediment concentrations.

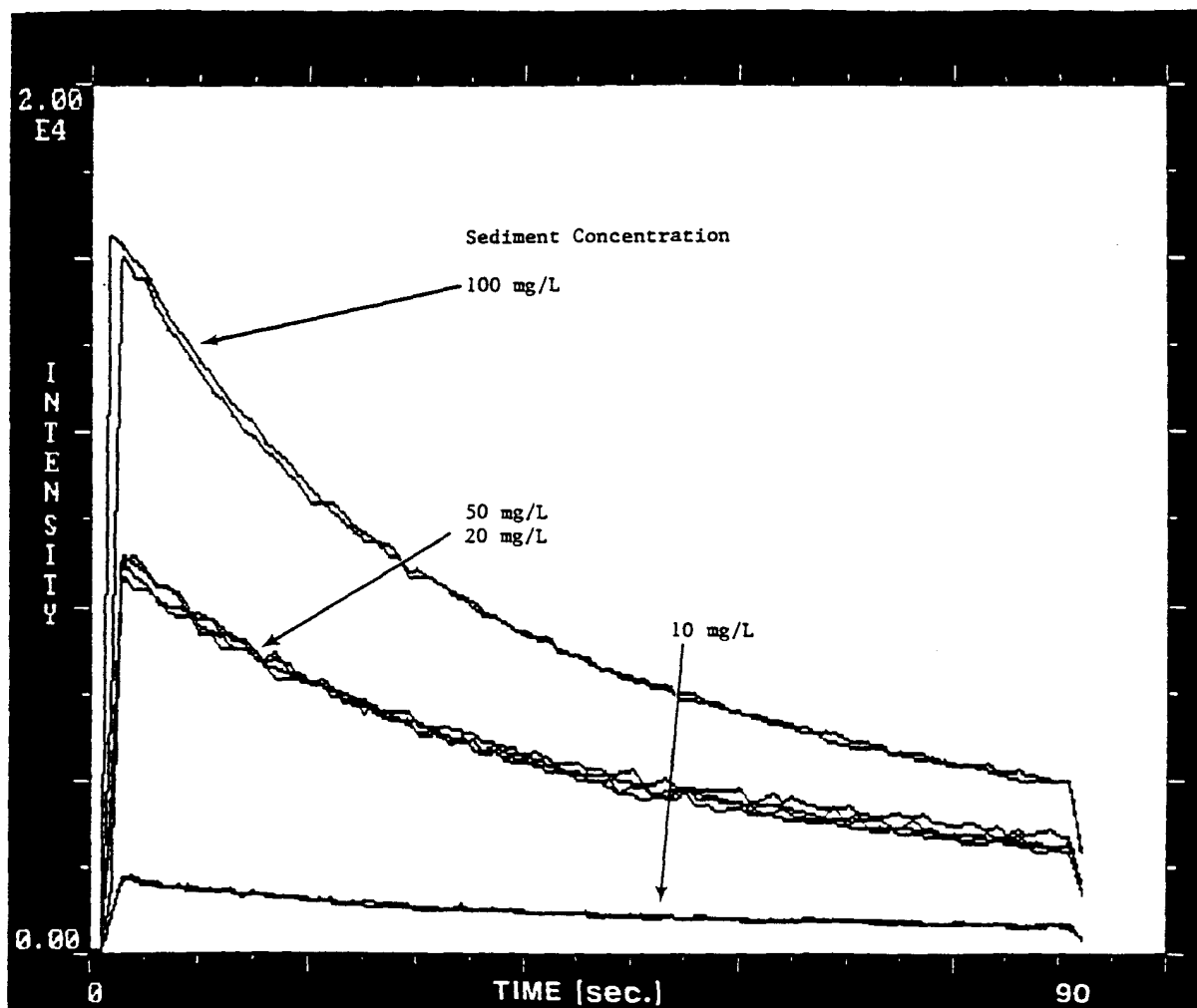


Figure 7. Example of infrared stimulated luminescence (IRSL) data collection curves. The data are plotted as stimulation time versus luminescence intensity. Two data curves are shown for each of the indicated sediment concentrations.

1994). Light emitted from a xenon arc lamp passes through a grating monochrometer which allows the operator to select the specific wavelength range that will reach the sample. A luminescence survey of the sample was conducted before collection of the RedSL data to find the optimum wavelength for sample stimulation. The luminescence signal emitted by the sample and the background noise for potential stimulation wavelengths were recorded and compared in 5 nm increments (Fig. 8). Light with a wavelength of 645 nm produced the strongest signal response in the sediment sample relative to the background noise within the red spectral range.

Sample disks were exposed to red light, 645 nm wavelength, for 90 seconds. The resulting luminescence signal emitted from the sample in the ultraviolet spectral range was measured by a photomultiplier tube and recorded as photon counts/sec. The photomultiplier tube was fitted with optical filters that transmit light in the ultraviolet range while excluding light from the visible wavelength range.

## 2.5 Data Analysis

Each suspension produced 3 to 8 disks for measurement by each luminescence stimulation technique (Table 1). An integrated luminescence signal was determined for each disk. The data were integrated at respective emission peaks of 250°C-280°C for TL, and seconds 3-7 for IRSL emission. The RedSL data were integrated across a larger signal range, seconds 3-59 of emission. A mean and a standard deviation for each disk set were calculated. These values were then scaled to the signal mean for the natural (unaltered) disk set for

# Lacustrine silty-clay; Lake Missoula MT

## VNB-OSL: Red Spectral Wavelength Survey

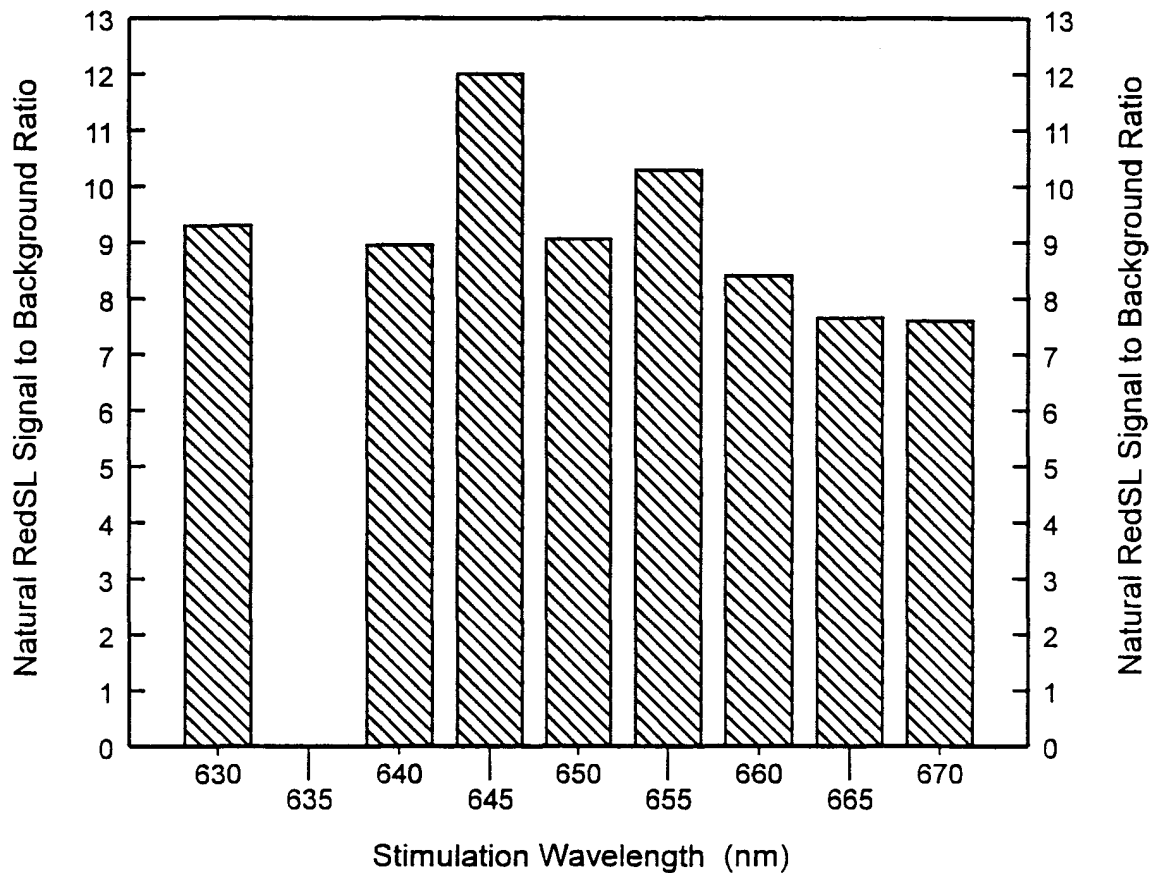


Figure 8. VNB-OSL wavelength survey; graph of the ratio of natural luminescence signal to background noise shown in 5 nm increments. A stimulation wavelength of 645 nm was selected to provide the optimum signal to noise ratio within the red spectral range. (The natural signal was not measured at 635 nm due to a prohibitively high background reading at that wavelength.)



each technique. The RedSL data were collected in two separate groups, due to recalibration of the VNB-OSL system during the course of the project. Table 4 shows the two analysis groups which are scaled to natural signal means; for data collected before and after system recalibration.

### **Section 3: Results / Discussion**

#### **3.1 The Effect of Sediment Concentration on Solar Resetting**

This investigation is in agreement with past qualitative observations that increasing suspended sediment concentration in turbid water systems corresponds to reduced potential for solar resetting of the luminescence signal. The quantitative determinations made in this investigation are presented in Tables 2, 3, & 4. Examination of the data from the flocculated trials in figures 9, 10, & 11 show a general increase in the percent of natural signal retained with increasing suspended sediment concentration for TL, IRSL, and RedSL. The RedSL signal response is a near linear increase in retained natural luminescence signal with increasing sediment concentration (Fig. 11). There is an indication of a RedSL signal response plateau between 20 and 50 mg/L. The IRSL data display a sharp increase in natural signal retained between sediment concentrations of 10 and 15 mg/L. The IRSL data also exhibit a signal response plateau for sediment concentrations between 15 and 75 mg/L (Fig. 10). The TL signal response is more chaotic but displays the same plateau as the IRSL signal response (Fig. 9). However, these signal response characteristics are not as pronounced in the TL data as in the

Table 2. Thermoluminescence Data Table

Flocculation Permitted		Integrated Photon Counts 250C -- 280C										Percent	
Sediment Concentration (mg/L)	Suspension Number	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	Disk 6	Disk 7	Disk 8	Mean	1 sigma	Natural	(+/-) 1 sigma
100	IV	1616180	1753488	1617094	935538	1179418	964396	1138719		1662254	64513	[100.0]%	+/- 4.7%
75	XIII	981560	915061	1023238	702813					1019847	94470	73.7%	+/- 6.8%
50	II	803845	596907	705484	309660					702762	72476	50.6%	+/- 5.2%
50	XIV	307516	221857	241527	702813					298287	63699	21.5%	+/- 4.6%
20	III	515567	797755	578160	602094					623394	105509	45.0%	+/- 7.6%
15	XV	737079	600045	870856						735993	110561	53.2%	+/- 8.0%
10	I	306586	384489	310816	434592					359121	53462	25.9%	+/- 3.9%
Natural Signal		1564047	1230041	1358602						1384230	137556	100.0%	+/- 9.9%

Flocculation Inhibited		Integrated Photon Counts 250C -- 280C										Percent	
Sediment Concentration (mg/L)	Suspension Number	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	Disk 6	Disk 7	Disk 8	Mean	1 sigma	Natural	(+/-) 1 sigma
75	VII	533556	569750	592477	504037					549955	33828	39.7%	+/- 2.4%
75	VIII	1137256	1316261	1190786	958777					1150770	128484	83.1%	+/- 9.3%
35	XI	175281	128313	135257	121420					140501	19518	10.2%	+/- 1.4%
20	X	581955	478761	651358						570691	70911	41.2%	+/- 5.1%
20	XII	75147	57786	72819						68594	7694	5.0%	+/- 0.6%
15	VI	110750	114112	103164	106951					108744	4098	7.9%	+/- 0.3%
15	IX	122892	146917	137458						135756	9882	9.6%	+/- 0.7%
16hr. Full Sun		190239	144236	170614						168363	18848	12.2%	+/- 1.4%

Table 3. Infrared Stimulated Luminescence Data Table

Flocculation Permitted		Integrated Photon Counts: (sec. 3 - 7)										Percent	
Sediment Concentration (mg/L)	Suspension Number	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	Disk 6	Disk 7	Disk 8	Mean	1 sigma	Natural	(+/-) 1 sigma
100	IV	64466	70552	62640	61715					64843	3441	81.3%	+/- 4.3%
75	XIII	29558	37860	33418	30856	33089	34587	30710	32917	32874	2447	41.2%	+/- 3.1%
50	II	37586	35297	35072						35965	1136	45.1%	+/- 1.4%
50	XIV	10368	10258	8906	6877	8515	11337	6402	7263	8741	1692	11.0%	+/- 2.1%
20	III	33360	38324	28035	33957					33424	3652	41.9%	+/- 4.6%
15	XV	28929	30263	26514						28569	1552	35.8%	+/- 1.9%
10	I	6413	6311	6927	12108					6550	270	8.2%	+/- 0.3%
10	XVI	10140	10615	11631						11124	783	13.9%	+/- 1.0%
Natural Signal		86456	76690	62121	93842					79777	11871	100.0%	+/- 14.9%

Flocculation Inhibited		Integrated Photon Counts: (sec. 3 - 7)										Percent	
Sediment Concentration (mg/L)	Suspension Number	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	Disk 6	Disk 7	Disk 8	Mean	1 sigma	Natural	(+/-) 1 sigma
75	VII	1626	1396	1756	1524					1576	132	2.0%	+/- 0.2%
75	VIII	19373	25675	21344	28199					23648	3479	29.6%	+/- 4.4%
25	XI	1002	590	1625	1077	949	1358	529	667	973	359	1.2%	+/- 0.4%
20	X	3967	4407	4679	4344					4349	254	5.5%	+/- 0.3%
20	XII	597	738	801						712	85	0.9%	+/- 0.1%
15	VI	908	813	605	553					720	146	0.9%	+/- 0.2%
15	IX	1120	2023	754	1618	1760				1455	457	1.8%	+/- 0.6%
4hr. Full Sun	V	2587	1664	2640	1668					2140	474	2.7%	+/- 0.6%



Table 4. Red (645 nm) Stimulated Luminescence Data Table

Floculation Permitted		Integrated Photon Counts (sec. 3-51)										Percent	
Sediment Concentration (mg/L)	Suspension Number	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	Disk 6	Disk 7	Disk 8	Mean	1 sigma	Natural	(+/-) 1 sigma
Analysis Group 1													
Natural Signal													
100	IV	83480	73562	63698	84869	76023				76326	7634	100.0%	+/- 10.0%
50	II	53531	61859	76241	59549	50691	68908			61797	8717	81.0%	+/- 11.4%
20	III	17798	20800	33622	20129	18544	26150			22841	5517	29.9%	+/- 7.2%
10	I	25583	17188	12406	14370					17387	5028	22.8%	+/- 6.6%
		5231	3522	6230	5625	6028				5327	966	7.0%	+/- 1.3%
Analysis Group 2													
Natural Signal													
75	XII	13076	14600	16400	15976	13574	17248	14502	13500	14860	1423	100.0%	+/- 9.6%
50	XIV	5080	6746	7198	7858	12850	10242	12990		8995	2861	60.5%	+/- 19.3%
15	XV**	3662	3340	5756	3026	3478	4036	4468	4140	3991	799	26.9%	+/- 5.4%
		6394	9198	11366	5442					8105	2344	54.5%	+/- 15.8%

\*\* Circulation cell within the Turbidity Tube was lost during timed exposure



## Thermoluminescence Data

4 Hours Exposure in Turbidity Tube

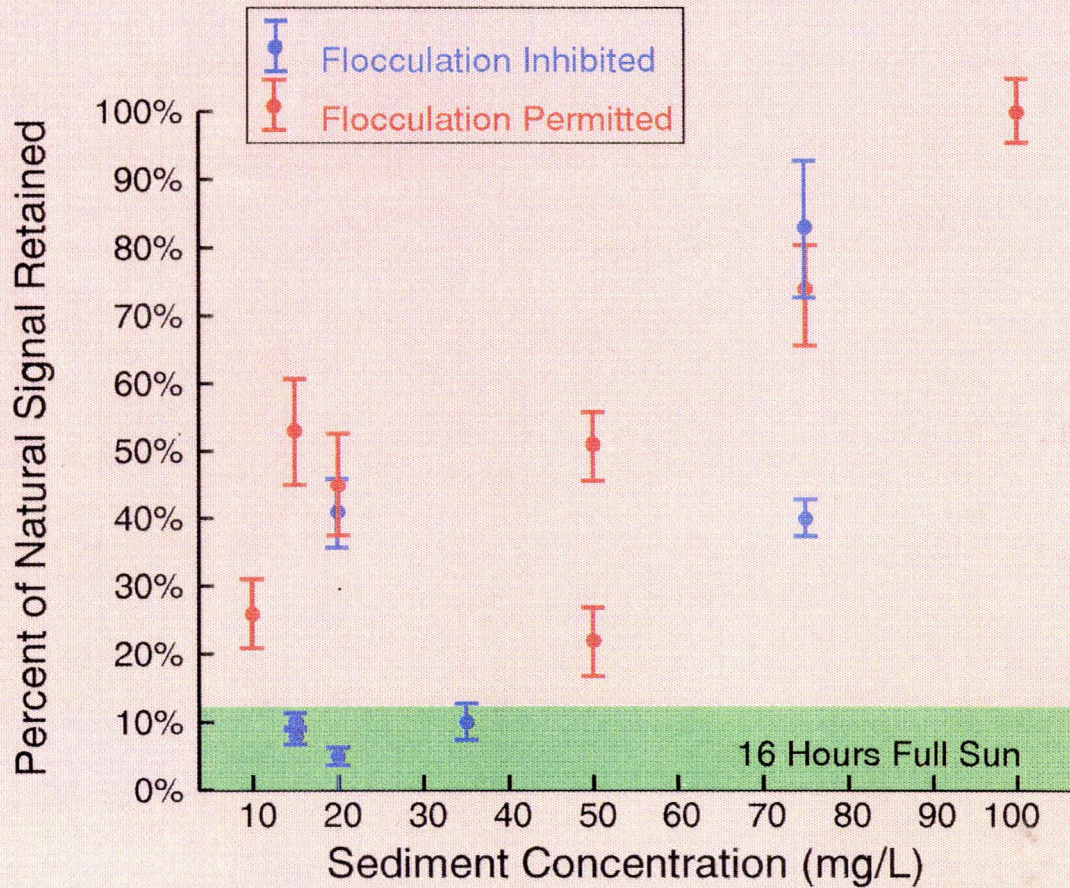


Figure 9. Graph of sediment concentration versus percent of natural TL signal retained after 4 hours exposure in T-tube. Data points shown in red represent suspensions in which flocculation was permitted. Data points shown in blue represent suspensions in which flocculation was inhibited by addition of a chemical dispersant. The Green zone depicts a signal level less than or equal to the retained natural signal after 16 hours of full sunlight exposure. 1 sigma error bars shown.



## Infrared Stimulated Luminescence Data

4 Hours Exposure in Turbidity Tube

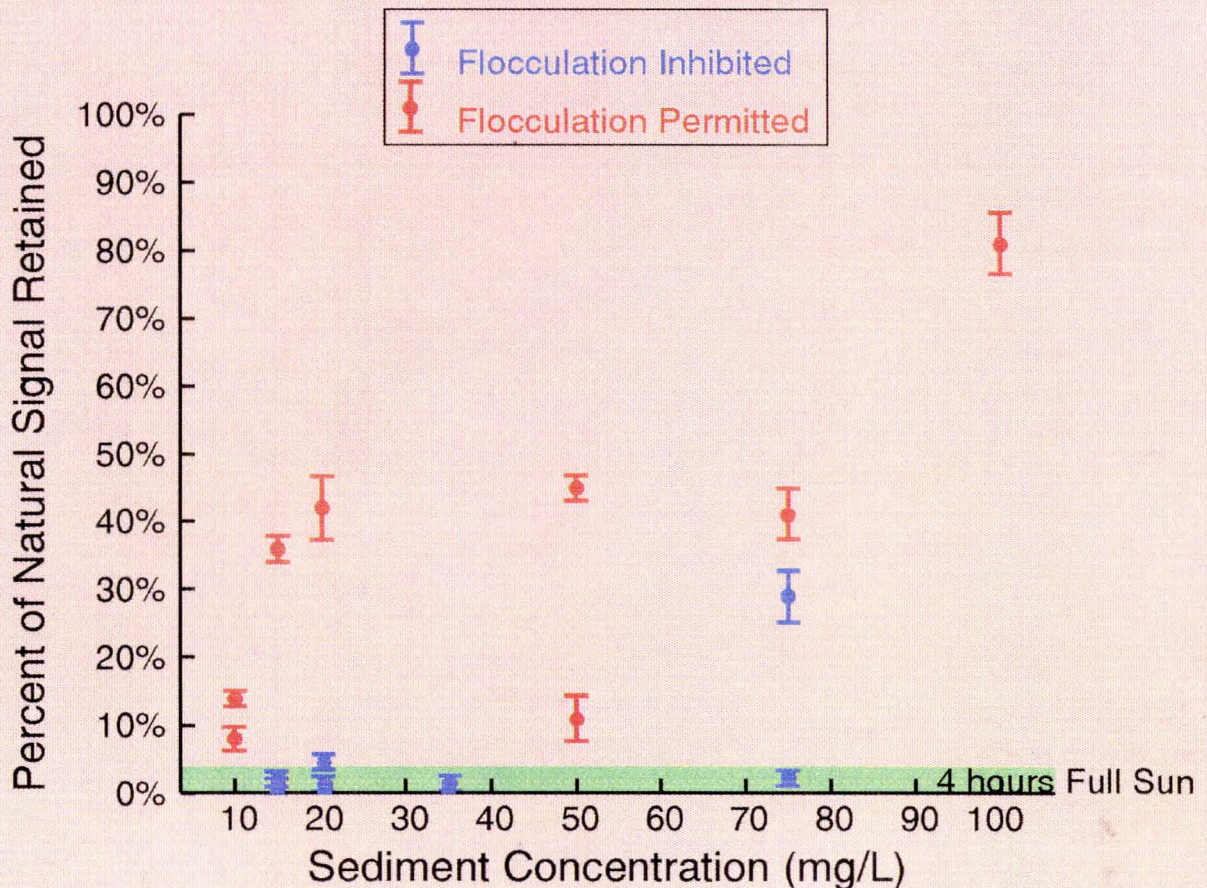


Figure 10. Graph of sediment concentration versus percent of natural IRSL signal retained after 4 hours exposure in T-tube. Data points shown in red represent suspensions in which flocculation was permitted. Data points shown in blue represent suspensions in which flocculation was inhibited by addition of a chemical dispersant. The Green zone depicts a signal level less than or equal to the retained natural signal after 4 hours of full sunlight exposure. 1 sigma error bars shown.



## Red (645nm) Simulated Luminescence Data

4 Hours Exposure in Turbidity Tube

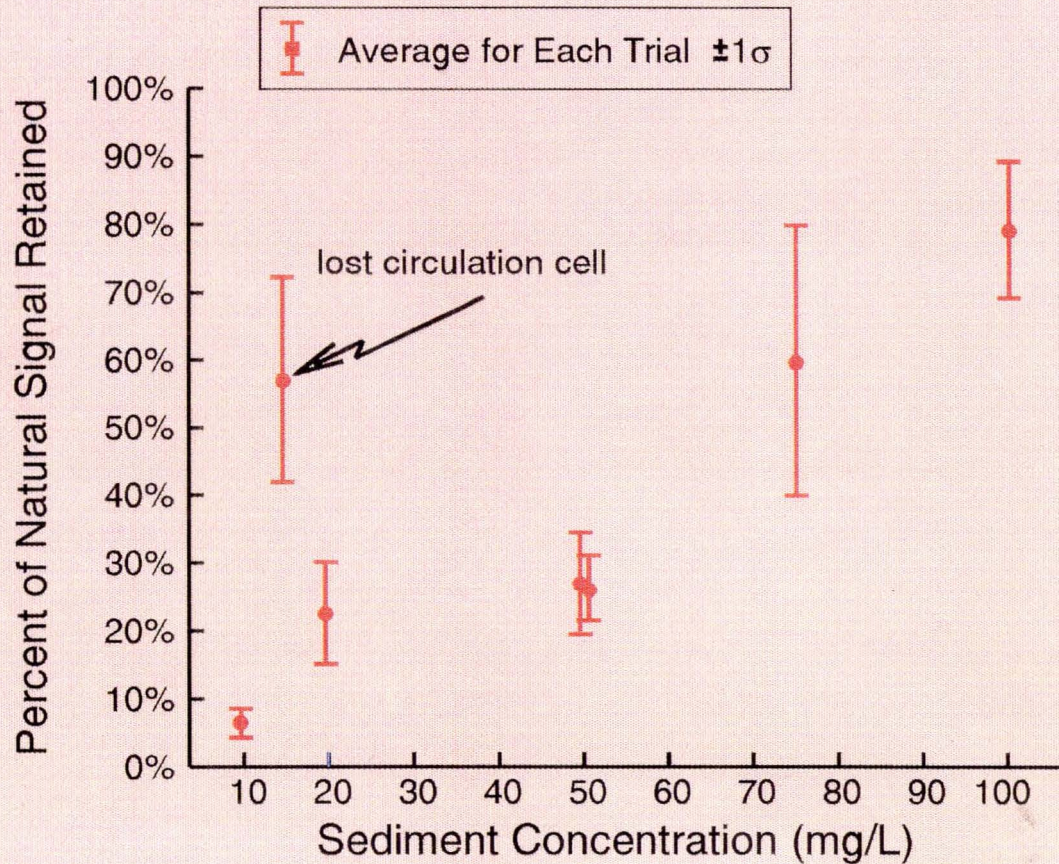


Figure 11. Graph of sediment concentration versus percent of natural RedSL signal retained after 4 hours exposure in T-tube. Data points shown in red represent suspensions in which flocculation was permitted. 1 sigma error bars shown.

IRSL data. The plateau in luminescence signal response indicated in all three data sets may reflect optical properties of sediment-laden water and/or mechanical properties of sediment motion in turbid water systems that are not well understood at this time.

### 3.2 The Effect of Flocculation on Solar Resetting

Experimental results indicate that flocculation has a significant effect on the solar resetting of the TL and IRSL signal in waterlain sediments. In most suspensions where flocculation was inhibited by addition of a dispersant the TL and IRSL signal retained by the mineral grains was indistinguishable from the comparative fully solar reset signal level (green shaded zones in Figs. 9 & 10). The results of this investigation suggest that flocculation in natural turbid water systems substantially inhibits the solar resetting of the luminescence signal in waterlain sediments. It may in fact be a primary process contributing to the retention of residual luminescence signal in waterlain sediments.

### 3.3 Comparative Sensitivity of Luminescence Stimulation Techniques

This investigation has provided a means of comparing the sensitivity of the three luminescence stimulation techniques (TL, IRSL, and RedSL) to the solar resetting of the luminescence signal in sediment grains suspended within a turbid water system. The sensitivity differences can be shown by a composite plot of the flocculated data sets from all three luminescence stimulation techniques (Fig. 12).



## Turbidity Tube Data

4 Hours Exposure, Flocculation Permitted

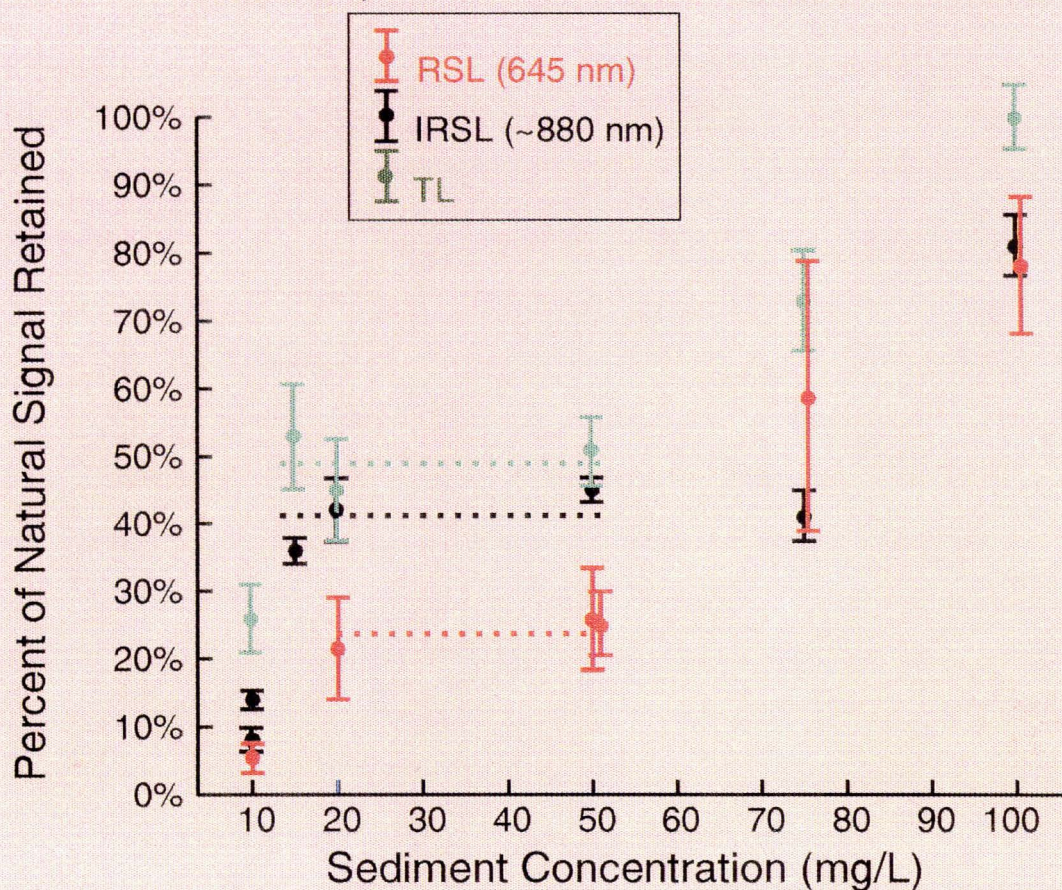


Figure 12. A composite graph of sediment concentration versus percent of natural luminescence signal retained after 4 hours exposure in T-tube. All data points are for flocculation permitted data sets. TL data points are shown in green, IRSL data points are shown in black, and RedSL data points are shown in red. The dotted lines indicate the signal responses plateaus. 1 sigma error bars shown.

Examination of the plot shows that for sediments transported and deposited in concentrations of less than 10 mg/L the RedSL and IRSL signals are well reset with ~10% or less of the natural luminescence signal retained after 4 hours exposure time. In contrast the retained natural TL signal at 10 mg/L is ~25%. The results also show that for suspended sediment concentrations of 15-50 mg/L, both IRSL and TL retain 40% to 50% natural luminescence signal after the same exposure period. The large residual and the lack of significant difference between IRSL and TL sensitivity in this concentration range provides insight into past tendencies for TL and IRSL age determinations to over-estimate the known age of waterlain sediments. The natural RedSL signal retained for sediment concentrations of 20-50 mg/L is between 20% and 25%. The difference between residual RedSL signal versus TL and IRSL signal for sediment concentrations of 20-50 mg/L underscores the need for continued research and development of procedures for the application of RedSL to date waterlain sediments. Lastly the results show that after 4 hours of exposure to natural sunlight, sediment suspended in concentrations greater than 50 mg/L generally retain greater than 50% of their natural luminescence signal regardless of the luminescence stimulation techniques employed. This suggests that sediments transported and deposited in concentrations greater than 50 mg/L retain a prohibitively large residual signal for reliable luminescence age determinations.

#### Section 4: Conclusion

The quantitative determinations made in this investigation show a general increase in the percent of natural signal retained (residual luminescence signal) with increasing suspended sediment concentration for TL, IRSL, and RedSL. The results also reveal a TL and IRSL signal response plateau between sediment concentrations of 20 and 50 mg/L. This plateau is also indicated in the RedSL data. Future investigation into the properties or processes that produce this signal response plateau may also increase our understanding of the solar resetting of the luminescence signal in turbid water systems.

Results of this investigation suggest that flocculation is a significant and perhaps a previously under-evaluated factor contributing to residual luminescence and thereby over-estimated luminescence age determinations for waterlain sediments. Continued characterization of the flocculation effect on other sediment samples is needed to confirm this determination.

The comparison of the sensitivity of TL, IRSL and RedSL to solar resetting gained by this investigation provides guidelines for prudent applications of the three luminescence stimulation techniques. Results of this experiment are in agreement with a large body of previous work indicating that TL cannot provide confident age determinations for waterlain sediments. The results also indicate that IRSL may provide reliable age determination for waterlain sediments if the depositional context of the sample can constrain potential



suspended sediment concentrations to be  $\leq 10$  mg/L. Additionally, the results indicate the increased sensitivity of the red simulated luminescence signal to solar resetting and highlight the potential application of RedSL to date waterlain sediments transported and deposited in concentrations up to 50 mg/L.

## References

- Aiken, M.J., 1985. Thermoluminescence Dating, Academic Press: New York, p359.
- Berger, G.W., 1988. Dating Quaternary events by Thermoluminescence. Easterbrook, D.J., ed.,: Geological Society of America Special Paper 227, p13-50.
- Ditlefsen, C., 1992. Bleaching of K-Feldspars in Turbid Water suspensions: a Comparison of Photo- and Thermoluminescence Signals. Quaternary Science Reviews, v.11, p33-38.
- Forman, S.L., 1989. Applications and Limitations of Thermoluminescence to Date Quaternary Sediments. Quaternary International, v.1, p47-59.
- Forman, S.L., 1990. Thermoluminescence Properties of Fiord Sediments From Engelsbutka, Western Spitsbergen, Svalbard: a New Tool for Deciphering Depositional Environment? Sedimentology, v.37, p377-84.
- Forman, S.L., Lepper, K., Pierson, J., 1994. Limitations of Infrared Stimulated Luminescence to Date High Arctic Marine Sediments. Quaternary Science Reviews, v.13, p.545-550.
- Klein, C., and Hurlbut, S.H. Jr., 1985. Manual of Mineralogy, John Wiley and Sons: New York, p596.
- Levish, D., Ostenaar, D., and Klinger, R., 1993. Quaternary Geology of the Mission Valley, Montana. Friends of the Pleistocene 1993 Rocky Mountain Field Trip Guide. Bureau of Reclamation, Denver, CO., Seismotectonic Report #93-7.
- Pickard, G., and Emery, W., 1984. Descriptive Physical Oceanography, Pergamon Press: New York, p249.
- Pierson, J., Forman, S.L., Lepper, K., Conley, G., 1994. A Variable Narrow Bandpass Optically Stimulated Luminescence System for Quaternary Geochronology. Radiation Measurements v.23 #2/3, p533-535.
- Stokes, S., 1992. Optical Dating of Young (Modern) Sediments using Quartz: Results from a Selection of Depositional Environments. Quaternary Science Reviews, v.11, p153-159.
- Syvitski, J., Burrell, D., Skei, J., 1987. Fjords Processes and Products, Springer-Verlag: New York, p379.